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Operation REDWING

PACIFIC PROVING GROUNDS

May - July 1956

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Project 8.2

THERMAL EFFECTS ON CELLULOSIC MATERIALS

Issuance Date: March 12, 1958

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HEADQUARTERS FIELD COMMAND, ARMED FORCES SPECIAL WEAPONS PROJECT
SANDIA BASE, ALBUQUERQUE, NEW MEXICO

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5) Forest Service, Washington D. C.

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Report on OPERATION REDWING—PROJECT 8.2

(U) THERMAL EFFECTS ON CELLULOSIC MATERIALS

(10)

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~~U. S.~~ Department of Agriculture
Forest Service
Division of Fire Research

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FOREWORD

This report presents the preliminary results of one of the projects participating in the military-effect programs of Operation Redwing. Overall information about this and the other military-effect projects can be obtained from WT–1344, the "Summary Report of the Commander, Task Unit 3." This technical summary includes: (1) tables listing each detonation with its yield, type, environment, meteorological conditions, etc.; (2) maps showing shot locations; (3) discussions of results by programs; (4) summaries of objectives, procedures, results, etc., for all projects; and (5) a listing of project reports for the military-effect programs.

ABSTRACT

The project had as its primary objectives the determination of (1) the minimum thermal-ignition energies for fine kindling fuels as a check on laboratory data obtained by the U. S. Forest Service (USFS) and the U. S. Naval Radiological Defense Laboratory (NRDL) and (2) the depth of char in wood as a check on equations developed from laboratory data obtained ~~by NRDL~~ with a carbon arc.

Test specimens of alpha-cellulose paper of various thicknesses, densities, and carbon contents; six common kindling fuels (cotton denim, rayon cloth, newspaper, pine needles, dry grass, and corrugated fiberboard); and three species of wood (maple, willow, and balsa) were exposed to the radiation from Shot Cherokee at Sites Dog and George. The specimens were exposed to thermal radiation directly and, also, behind attenuating screens of different transmissions. For different moisture contents, part of the specimens were in containers vented to the atmosphere and part in moisture-proof containers containing a desiccant. Because the bomb burst was not directly over planned target zero, the direct radiation from the entire fireball entered the cells at an appreciable angle, irradiating only a small portion of each specimen at Site George and missing the specimens entirely at Site Dog. For this reason, the depths of char of the wood specimens were without significance.

Data were obtained that permitted an estimate of the critical ignition energy for newspaper, pine needles, and ten of the black papers. Analysis of the black-paper data indicates that the minimum thermal energy causing ignition was increased by moisture content, density, and thickness raised to about the 0.7 power, also that moisture content and density had more effect on the critical ignition energy of the thick papers than of the thin papers.

The primacord technique of triggering a mechanism just before shot time was entirely successful and should prove useful in a wide variety of applications in future test operations.

PREFACE

Project 8.2 of Operation Redwing was a cooperative endeavor between the California Forest and Range Experiment Station (CFRES) and the Forest Products Laboratory (FPL) of the U. S. Forest Service (USFS), and the U. S. Naval Radiological Defense Laboratory (NRDL) of the Department of the Navy. Preplanning, laboratory measurements, procurement, and reporting were done jointly by the following members of the cooperating organizations: F. M. Sauer, formerly of the USFS; C. P. Butler, W. B. Plum, and W. Lai, of NRDL; H. D. Bruce, of FPL; and W. L. Fons, of CFRES. Overall direction was by W. L. Fons, the project officer.

Sample containers and exposure racks were designed by CFRES and NRDL personnel. Equipment was procured and assembled by S. S. Richards of CFRES. Typing of report was done by V. M. Burke of CFRES. Supplementary thermal measurements were made by NRDL, Project 8.1. Transmissions of screens and laboratory measurements of the critical ignition energies for black alpha-cellulose papers were by FPL. Preshot and postshot documentary still photography was made by Task Unit 8. The underground shelter designed by J. R. Nichols, of NRDL, was made available to Project 8.2 by Alexander Julian, of Project 8.4.

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Chapter I
INTRODUCTION

1.1 OBJECTIVES

The project was part of the research program sponsored by the Armed Forces Special Weapons Project (AFSWP) to study the extent and distribution of ignitions by thermal radiation (References 1, 2, and 3) from nuclear explosions over urban and forest areas. Its immediate objectives were to determine: (1) critical ignition energies of alpha-cellulose papers by large-yield nuclear bursts as a check on laboratory data by the U S. Forest Service (USFS) and the Naval Radiological Defense Laboratory (NRDL) (Reference 4); (2) depth of char in three species of wood of different densities by large-yield bursts as a check on data obtained by NRDL with a laboratory source (References 5 and 6); and (3) the minimum radiant energies required to ignite selected common urban and forest kindling fuels for comparison with ignition energies obtained by laboratory sources (References 9 and 10).

1.2 BACKGROUND

Previous work with nuclear devices in the kiloton-yield range by the California Forest and Range Experiment Station (CFRES) and the Forest Products Laboratory (FPL) of the USFS showed that many natural fuels in urban and forest areas can be set afire by thermal radiation from nuclear bursts (References 1, 3, 7, and 8) beyond the range of blast damage. Studies have shown that massive materials, such as lumber, plywood, and roofing, will not be ignited by thermal radiation from a nuclear explosion, at least beyond the circle of complete destruction (Reference 8). However, fine kindling materials, such as fabrics, paper, and dead grass and foliage, may be ignited, and an urban or a forest conflagration may result. At FPL, experimental work has been done with a laboratory source on ignition of combustible materials with both short and long pulse times (References 9 and 10).

Tests have been made at NRDL with a square-wave pulse on black paper (alpha-cellulose with 2.5 percent carbon) of two densities, and the minimum thermal energies for sustained ignition of the black papers were correlated against exposure time on a nondimensional basis covering a range of irradiance from 2 to 25 cal/cm^2-sec, pulse times from 0.1 to 4 seconds, and paper thicknesses from 2 to 30 mils (References 4 and 17). These correlations were made with data obtained by laboratory sources, but no information has been available on the ignition energies of these papers when exposed to the radiation from a nuclear detonation.

Depth-of-char measurements were made on two species of wood during Operation Buster-Jangle (Reference 11). Laboratory measurements on several different species of wood exposed under conditions of constant irradiation have been reported (References 12 and 13). Depth of char was measured in the laboratory on cottonwood (Reference 14), using a simulated field pulse (Reference 15), and on one species of wood, Guatemalan cedar, during Operation Teapot. Equations were developed which allow prediction of char depth for a given yield of burst (Reference 5).

Chapter 2

PROCEDURE

Specimens of the materials to be tested were mounted in metal boxes, each in an individual cell to separate it from others. The boxes were kept closed until a few seconds before shot time to protect the specimens from the weather. The air in about half the boxes was kept dry; the air in the other boxes was the humid, ambient air. The specimens, boxes, cells, and technique for opening the boxes and exposing the specimens are described in this chapter.

2.1 CHARACTERISTICS OF ALPHA-CELLULOSE PAPERS

The Forest Products Laboratory manufactured for NRDL alpha-cellulose papers of eight thicknesses, two densities, and four carbon contents (Reference 18). These papers were chosen as idealized fuels possessing properties of interest in the problem of ignition of fine fuels. Since the papers were made from a single batch of very-pure alpha-cellulose pulp under controlled conditions, the different papers were comparable and their variables could be examined independently. Thus, by exposing two samples, identical except for one variable, the effect of the variable could be ascertained.

A carbon content of 2.5 percent was ample to make the paper appear black; with more carbon the papers would have become fragile, with no appreciable increase in the optical-absorption properties. The reflectivities of two of the papers included in the tests, one with no carbon and one with 2.5 percent carbon, are shown in Figure 2.1.

Fifteen of the black papers and fifteen of the white alpha-cellulose papers were exposed to Shot Cherokee. The characteristics of these thirty alpha-cellulose papers are given in Table 2.1.

2.2 CHARACTERISTICS OF THE URBAN AND FOREST MATERIALS

From combustible materials previously tested, six representative types in common occurrence in urban and forest areas were selected by AFSWP for exposure to Shot Cherokee. Their characteristics are given in Table 2.2.

2.3 CHARACTERISTICS OF THE WOOD SPECIMENS

Maple, heart willow, and balsa were selected for the depth-of-char experiments. The selection was based on uniformity in grain structure and wide differences in density. Heart willow was chosen because its density is close to that of common building species, such as fir and pine.

The lumber was cut with the growth rings nearly parallel to the surface to expose as uniform a grain as possible to the radiation. All like wood specimens were cut from the same piece of lumber.

The physical characteristics of all wood specimens are given in Table 2.3.

2.4 ATTENUATING SCREENS

It was not possible to locate stations at many different distances from ground zero for exposing specimens to various levels of radiant energy. Variations of energy were

TABLE 2.1 CHARACTERISTICS OF ALPHA-CELLULOSE PAPERS

Code	FPL Paper No.	Thickness, mil	Code	FPL Paper No.	Thickness, mil
White:			Black ($2\frac{1}{2}$ percent carbon):		
Specific Gravity, 0.55; Thermal Conductivity*, 1.7×10^{-4} (cgs units); EMC†, 1.61 percent, over silica gel, 80 F; EMC, 22.8 percent, at RH 95 percent and 80 F.			Specific Gravity, 0.55; Thermal Conductivity*, 1.7×10^{-4} (cgs units); EMC†, 1.64 percent, over silica gel, 80 F; EMC, 24.3 percent, at RH 95 percent and 80 F.		
1	4,225	3.8	16	4,098	3.9
2	4,199	5.9	17	4,099	5.9
3	4,200	7.9	18	4,100	8.0
4	4,201	10.0	19	4,101	9.7
5	4,202	12.1	20	4,102	11.6
6	4,203	20.3	21	4,103	20.2
7	4,204	31.3	22	4,104	30.3
Specific Gravity, 0.75; Thermal Conductivity, 2.3×10^{-4} (cgs units); EMC, 1.56 percent, over silica gel, 80 F; EMC, 21.7 percent, at RH 95 percent and 80 F.			Specific Gravity, 0.75; Thermal Conductivity, 2.3×10^{-4} (cgs units); EMC, 1.57 percent, over silica gel, 80 F, EMC, 23.1 percent, at RH 95 percent and 80 F.		
8	4,226	2.1	23	4,097	2.1
9	4,205	4.3	24	4,090	4.1
10	4,206	6.3	25	4,091	6.1
11	4,207	8.2	26	4,092	8.3
12	4,208	10.0	27	4,093	10.1
13	4,209	12.7	28	4,094	12.3
14	4,210	21.1	29	4,095	20.3
15	4,211	32.1	30	4,096	31.5

* Measured by Institute of Engineering Research, University of California, Berkeley, California, with specimens at 3 percent moisture content.

† EMC: Equilibrium moisture content based on oven dry weight.

TABLE 2.2 CHARACTERISTICS OF SELECTED URBAN AND FOREST MATERIALS

Code	Material	Thickness	Weight per Unit Area	Specific Gravity	Moisture Content	
					Dry*	Ambient†
		mil	gm/ft² ‡			
N	Newspaper, finely printed want-ad section	3.3	4.64	0.59	1.3	37.0
D	Cotton denim, indigo blue	26.8	27.69	0.44	0.9	21.4
R	Rayon suiting, charcoal gray	15.0	15.09	0.43	1.6	36.1
C	Corrugated kraft fiberboard	125.0 §	96.0	0.33	1.1	33.0
G	Grass, Fescue sp., mainly young fox fescue, Festuca Megazura, yellow	2 to 9 (av. 4)	—	0.53	2.0	77.0
P	Pine needles, ponderosa, dead, brown	15 to 30 (av. 23)	—	0.51	2.1	33.4

* Over silica gel at 80 F.

† About 97 percent relative humidity and 80 F.

‡ Oven-dry.

§ Front kraft paper face, 14.4-mil thick; rear kraft paper sheet, 13.4-mil thick; total thickness 125 mil.

achieved, however, by exposing the specimens at one station with various neutral attenuators in front of them. Metal screens were chosen for this purpose, because they (1) are not combustible, (2) are not spectrally selective, (3) do not distort during the thermal pulse, and (4) provide nearly uniform illumination when set far in front of the specimen.

Wire screens having transmissions of 66.8, 66.3, 48.5, 37.0, and 23.8 percent were selected for the attenuators. In some cases two screens were used.

The wire diameters were measured, and the lengths of the umbras were calculated. The exposure cells to hold the specimens were so designed that the specimens would be

TABLE 2.3 CHARACTERISTICS OF WOOD SPECIMENS

	Maple	Willow	Balsa
Code	M	W	B
Specific gravity*	0.70	0.44	0.13
Thickness, inches	0.62	0.63	0.75
Thermal conductivity†, (c.g.s. units × 10^4)	5.2	3.7	1.4
Moisture content* dry conditions, percent	1.0	1.3	0.6
Moisture content* ambient conditions, percent	21.1	19.7	19.6

* Measured by California Forestry Research and Experiment Station, Berkeley, California.
† Measured by Institute of Engineering Research, University of California, Berkeley, California, with specimens at 3-percent moisture content.

many times the length of the umbra behind the screen, so that no shadow would be cast and variations of illumination across the plane of the specimen would be negligible. The transmissions of the screens were measured in the laboratory by FPL (Reference 16), singly or in combination, with a photoelectric cell and a disk light source subtending an

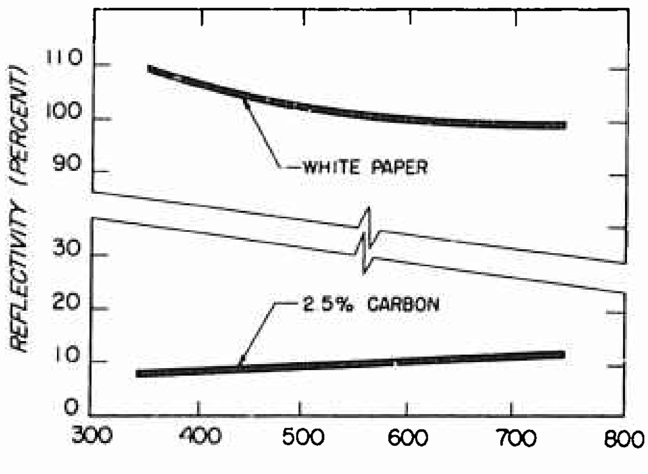

Figure 2.1 Reflectivity of alpha-cellulose papers relative to vitriolite standard.

angle of 19 degrees. Allowance was thus made for the effect of angle of incidence of the radiation from a large-scale fireball on the transmission of the screen. Mounted in this way, the calorimeter sensing element of $^3/_8$-inch diameter was exposed behind the screens in the same manner as we[illegible] the specimens in the field. From these energy measurements

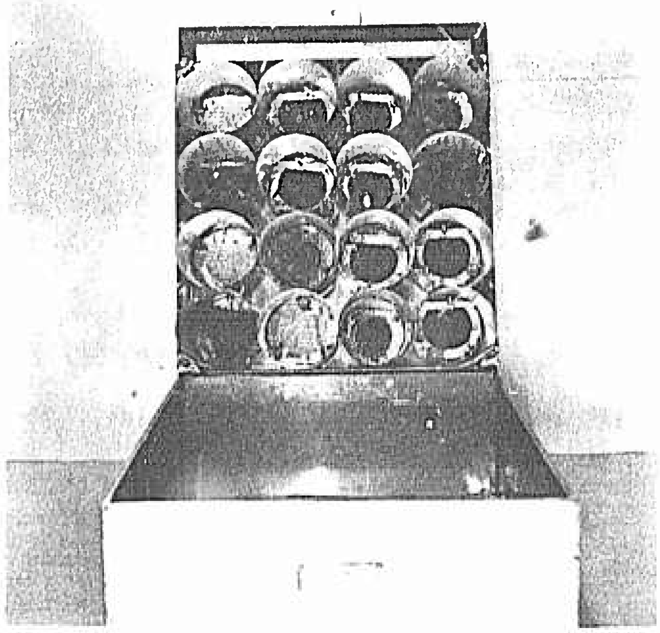

Figure 2.2 Specimens box showing truncated specimens mounted in cells in the box lid.

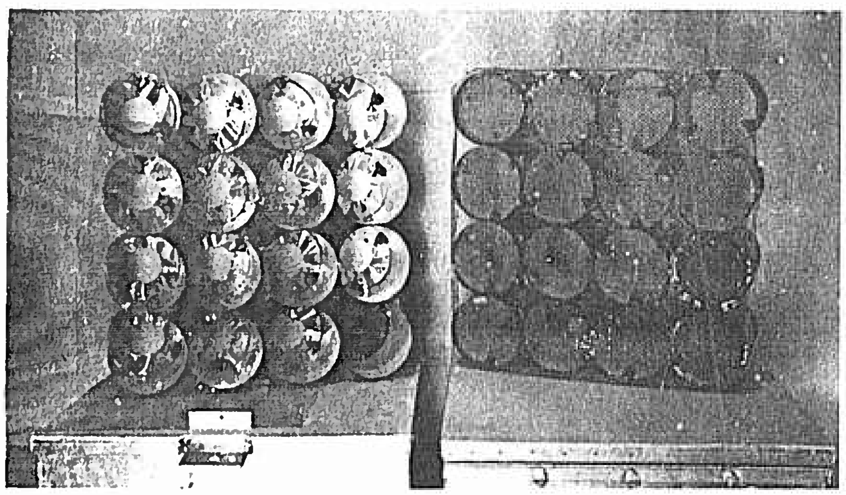

Figure 2.3 Exposure cells removed from boxes showing attenuating screen at left and back stop screen at right.

the screen transmissions could be computed (Reference 16). Furthermore, in the field, calorimeters were mounted behind the screens in the same manner as were the test specimens, in order to permit calculation of the screen transmissions from field energy measurements.

2.5 SPECIMENS

Some of the test materials were prepared in the form of specimens shown in Figure 2.2, appreciably smaller in diameter than the cells and truncated to allow ready dissipation of smoke. The cut surfaces of the cloth, paper, and corrugated fiberboard were protected by rings of aluminum foil (Figures 2.2 and 2.3). The specimens of wood were not so pro-

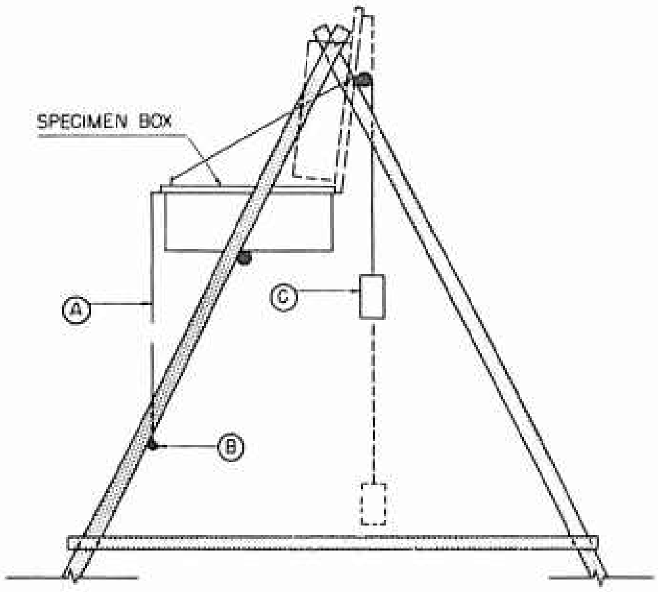

Figure 2.4 Elevation view of specimen box mounted on the A frame; A, wire holding down box lid; B, glass tube containing primacord; C, 15-pound weight, which opens lid when glass tube breaks.

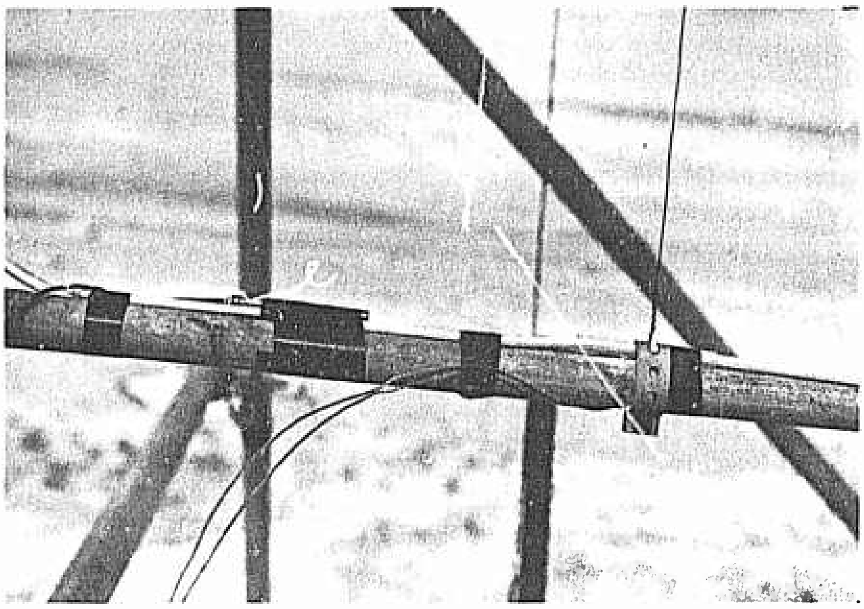

Figure 2.5 Photograph of the release apparatus, indicated at B in Figure 2.4. The blasting cap, left of center, is taped to the primacord (white cord running along top of horizontal $\frac{3}{4}$-inch pipe) which passes through the short glass tube strapped by metal plumbers' tape to the pipe. The vertical wire, right of center, is fastened to the glass tube and holds down the lid of a specimen box (above, out of view of photograph) until primacord detonation shatters the glass tube.

tected, as it was planned to neglect the edges when depth of char was measured. The grass and pine needles were mounted in cups of noncombustible plastic.

2.6 EXPOSURE CELLS AND BOXES

Cylindrical sheet-metal cells 4 inches in diameter and 6 inches long were made to hold the specimens. The inside surface of the cells were painted with a heat-resistant, flat-white paint to diffuse the light in order to avoid concentrations of the radiation by reflection from the cylindrical surface. Sheet-metal boxes 17 by 21 inches and 7 inches deep were made to hold the cells, sixteen to a box. A box with cells containing mounted specimens is shown in Figure 2.2. Figure 2.3 shows two sets of cells removed from their boxes, revealing a fine attenuating screen placed in front of the cells (left view) and a coarse back-stop screen at the rear of the cells (right view). The purpose of the backstop screen was to prevent flames from rising from one cell to neighboring cells. It was spaced ½ inch from the inside of the lid to allow room for passage of smoke from the cells.

Half of the boxes were provided with rubber gaskets between the lid and the body to form an air-tight joint when the box was closed. Silica gel was poured onto the bottom of these boxes in order to maintain a low moisture content in the specimens. The other half of the boxes had holes drilled in the bottoms and were without gaskets or dessicant; their specimens had the high moisture content provided by the ambient atmospheric conditions of the Eniwetok Proving Ground (EPG). Atmospheric relative humidity and temperature were recorded by a hygrothermograph in the same position as the exposure boxes.

The test specimens were mounted on three triangular metal tabs (Figure 2.3, right), which protruded from the walls of each cell. The specimens were fastened to the tabs by small screws or by two-prong brass paper fasteners. Specimens were mounted so that the angle subtended by the rim of the cell was the same for wood, paper, and cloth. The field of view from the center of each flat specimen was 45 degrees. For the grass and pine needles, the field of view was wider, since they extended beyond the plane of the flat materials. It was estimated that satisfactory thermal effects could not be observed if the position of detonation was in error more than one fireball diameter on either side of the planned target.

2.7 METHOD OF OPENING BOXES

Each box lid was held closed by a single strand of wire (A) with the end attached to a 10-mm-diameter pyrex tube 2.5 inches long fastened by a metal strap to a ¾-inch pipe (B) (Figures 2.4 and 2.5). Primacord was laid along the ¾-inch pipe and threaded through the glass tubes (Figure 2.5). Just prior to bomb detonation, the glass tube was ruptured by the firing of the primacord, which permitted the box lid to be opened by a 15-pound weight (C) (Figure 2.4).

The firing circuit for detonating the primacord was electrically connected to an Edgerton, Germeshausen, and Grier (EG&G) relay located in an underground shelter at each station. When the relay closed, 18 volts, provided by twelve dry cells, sent current through shielded cables from the shelters to the blasting caps taped to the primacord (Figure 2.5). To safeguard against misfire, two caps were used at Site Dog and four caps at Site George.

2.8 EXPOSURE RACKS AND SPECIMEN-BOX MOUNTING

Exposure racks were constructed of 1½-inch iron pipe, fastened with Tublox fittings, in the form of multiple A frames. The horizontal pipes forming the base of the frames

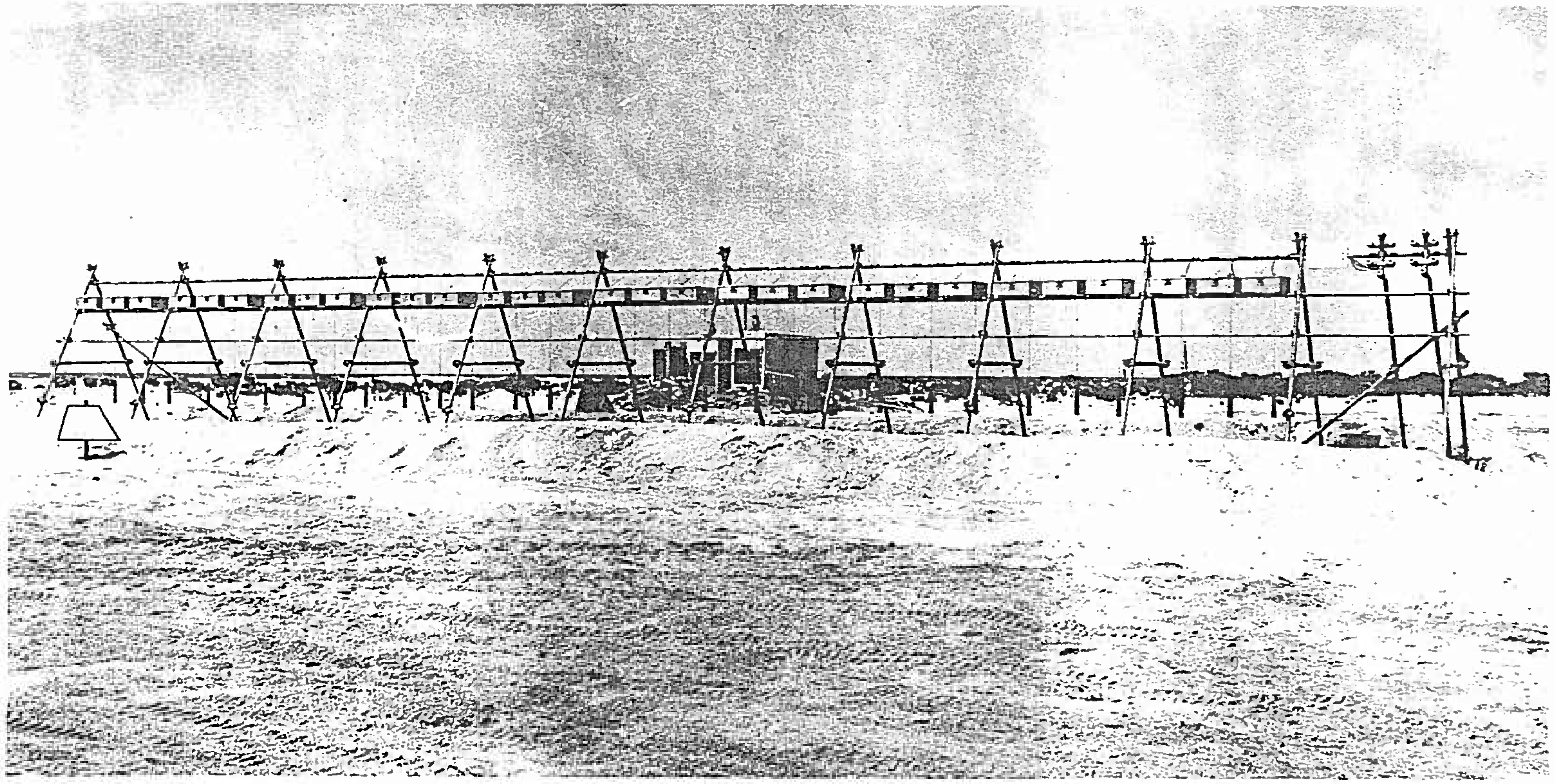

Figure 2.6 Thirty specimen boxes, hygrothermograph, and calorimeters mounted on the A frame at Site George.

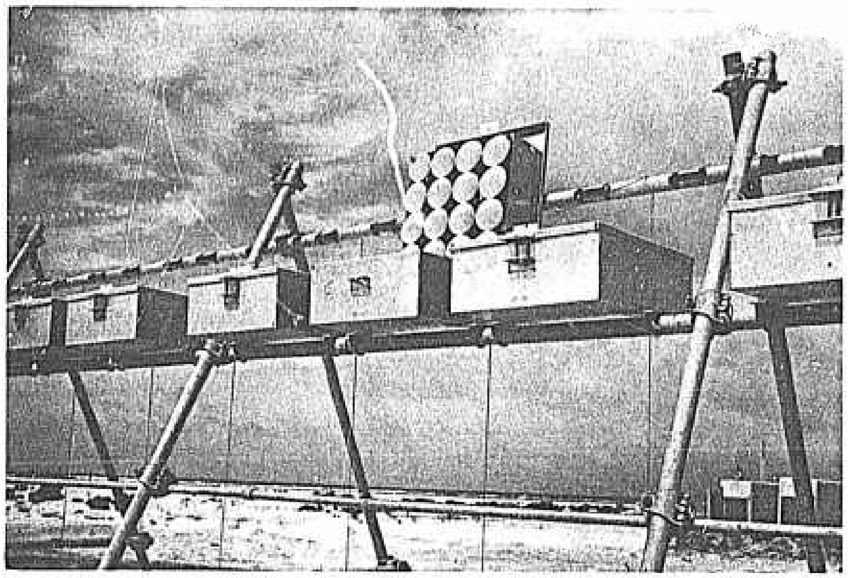

Figure 2.7 Specimen boxes at Site George, showing one box open with cells directed toward expected point of burst.

Figure 2.8 Specimen boxes at Site Dog mounted with primacord ready for detonation.

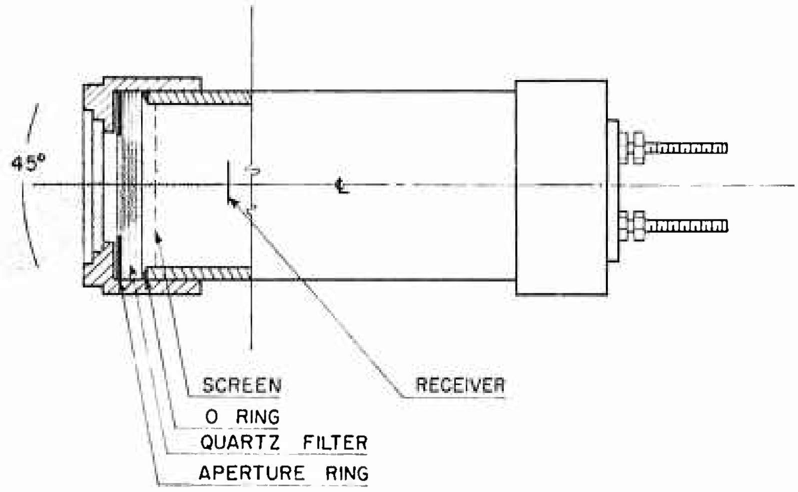

Figure 2.9 Calorimeter, 45-degree field of view, with attenuating screen mounted in calorimeter case.

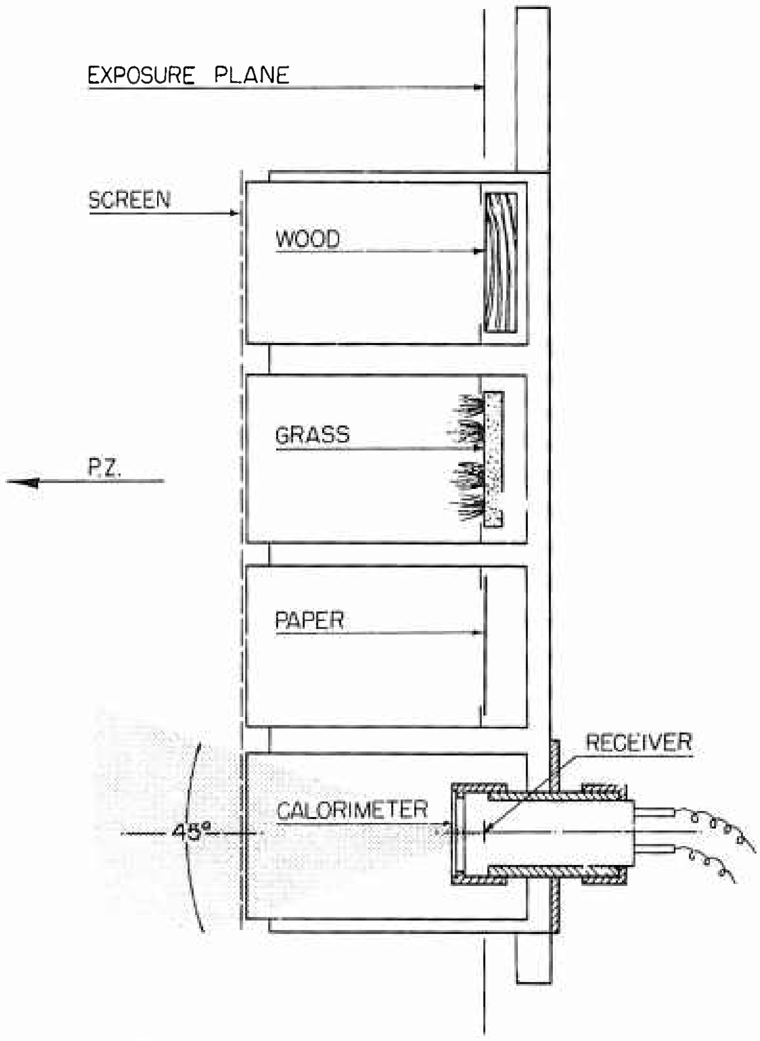

Figure 2.10 Cross-section of specimen box, showing four cells with mounted specimens and calorimeter.

TABLE 2.4 DISTRIBUTION OF SPECIMENS* IN SPECIMEN BOXES AT SITE GEORGE, SHOT CHEROKEE

Cell	Box Number														
No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	dry†	dry	amb‡	amb	dry	dry	amb	amb	dry	dry	amb	amb	dry	dry	amb
1	1	N	16	N	N	16	N	1	W	R	W	R	1	16	1
2	2	P	17	P	P	17	P	2	W	N	W	N	2	17	2
3	3	D	18	D	N	18	N	3	W	N	W	N	3	18	3
4	4	P	19	P	P	19	P	4	—	G	—	G	4	19	4
5	5	G	20	G	R	20	R	5	M	N	M	N	5	20	5
6	6	D	21	D	D	21	D	6	M	G	M	G	6	21	6
7	7	R	22	R	G	22	G	7	M	P	M	P	7	22	7
8	8	D	23	D	N	23	N	8	—	R	—	R	8	23	8
9	9	N	24	N	D	24	D	9	B	G	B	G	9	24	9
10	10	R	25	R	R	25	R	10	B	N	B	N	10	25	10
11	11	D	26	D	R	26	R	11	B	D	B	D	11	26	11
12	12	R	27	R	G	27	G	12	—	D	—	D	12	27	12
13	13	G	28	G	G	28	G	13	—	R	—	R	13	28	13
14	14	P	29	P	P	29	P	14	—	G	—	G	G	29	G
15	15	R	30	R	D	—	D	—	—	R	—	R	N	—	N
16	—	P	C	P	R	C	R	—	—	P	—	P	—	C	D

Cell No.	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
	amb	dry	amb	dry	dry	amb	amb	dry	amb	dry	dry	amb	amb	dry	amb
1	16	W	W	1	16	1	16	W	W	1	16	1	16	W	W
2	17	W	W	2	17	2	17	W	W	2	17	2	17	W	W
3	18	W	W	3	18	3	18	W	W	3	18	3	18	W	W
4	19	—	—	4	19	4	19	—	—	4	19	4	19	N	—
5	20	M	M	5	20	5	20	M	M	5	20	5	20	M	M
6	21	M	M	6	21	6	21	M	M	6	21	6	21	M	M
7	22	M	M	7	22	7	22	M	M	7	22	7	22	M	M
8	23	—	—	8	23	8	23	—	—	8	23	8	23	G	—
9	24	B	B	9	24	9	24	B	B	9	24	9	24	B	B
10	25	B	B	10	25	10	25	B	B	10	25	10	25	B	B
11	26	B	B	11	26	11	26	B	B	11	26	11	26	B	B
12	27	—	Ca§	12	27	12	27	—	Ca§	12	27	12	27	N	Ca§
13	28	D	—	D	28	—	D	—	—	G	28	N	N	—	N
14	29	P	—	P	D	13	P	—	—	N	N	G	G	—	G
15	P	—	—	13	P	D	28	—	17	13	G	13	28	—	N
16	C	—	—	C	—	P	29	—	C	14	C	14	C	G	G

*See Code in Table 2.1 for alpha-cellulose papers; see Code in Table 2.2 for urban and forest materials; see Code in Table 2.3 for wood.

†Dried over silica gel.

‡Ambient atmosphere at about 97 percent relative humidity and 80 F; measured by hygrothermograph at shot time.

§Ca, Calorimeter.

extended about 4 feet in front and to the rear. They were covered with plywood and weighted down with sand to keep the frame from being moved by the blast wave (Figures 2.6 and 2.8).

At Site George, thirty boxes were mounted as shown in Figure 2.6. A closer view of one bay with one box open is shown in Figure 2.7. At Site Dog, three boxes were mounted as shown in Figure 2.8.

2.9 SPECIMEN DISTRIBUTION

The distribution of specimens in each of the cells in all boxes is given in Table 2.4 for Site George and in Table 2.5 for Site Dog.

2.10 THERMAL INSTRUMENTATION

At Site George, calorimeters were mounted behind screens having transmissions of 66.3, 48.5, and 37.0 percent. Three calorimeters were exposed with no screen. All the

TABLE 2.5 DISTRIBUTION OF SPECIMENS IN SPECIMEN BOXES AT SITE DOG, SHOT CHEROKEE

Cell	Box Number		
No.	31	32	33
	ambient*	dry	ambient
1	3†	C‡	C
2	4	C	C
3	5	C	C
4	6	C	C
5	7	C	C
6	18	C	C
7	19	C	C
8	20	C	C
9	21	C	C
10	22	C	C
11	W§	C	C
12	M	C	C
13	B	C	C
14	M	C	C
15	W	C	C
16	B	C	C

* Ambient atmosphere at about 97 percent and relative humidity at 80 F; measured by hygrothermograph at shot time, Site George.
† See Code in Table 2.1 for alpha-cellulose papers.
‡ See Code in Table 2.2 for urban and forest materials.
§ See Code in Table 2.3 for woods.

calorimeters had a field of view of 45 degrees, as measured from the center of the receiver disk. Calorimeters mounted on the A frame are shown in Figure 2.6. A diagram of a calorimeter and its screen mounted on the A frame is shown in Figure 2.9. A diagram of a calorimeter mounted in a specimen box is shown in Figure 2.10. Thus, the energy measured by the calorimeter would be the same as the energy at the center of the exposure plane of each flat specimen.

The thermal energy received by the calorimeters was registered on a Heiland oscillograph located in the underground shelter. The oscillograph was started at H−5 seconds by an EG&G relay.

Chapter 3
RESULTS

3.1 CALORIMETRY

The results of the thermal measurement of Project 8.2 at Site George for Shot Cherokee are given in Table 3.1.

3.2 URBAN AND FOREST FUELS

The observed effects of the thermal radiation on the urban and forest fuels are shown in Table 3.2. Specimens of rayon cloth charred by exposure to the shot are shown in Figure 3.1. Estimates of the minimum thermal ignition energy values for the urban and forest fuels exposed to Shot Cherokee are given in Table 3.3.

3.3 ALPHA-CELLULOSE SPECIMENS

Reasonably good results were obtained on the black alpha-cellulose papers at Site George where 50 of the 111 specimens of black paper exposed were ignited, as shown in Table 3.4. Ignition and degrees of charring of black alpha-cellulose paper are shown in Figure 3.2. For most of the test materials, some specimens ignited and others charred, so that minimum ignition energies can be bracketed from the data.

It was expected that the white papers would be less easily ignited than the black papers, because of their differences in spectral reflectance, and whereas a large portion of the black papers were ignited, none of the white alpha-cellulose papers showed even slight char.

The results for the black alpha-cellulose paper were analyzed by estimating the thicknesses of paper that would be barely ignited by the various levels of radiant energy incident on the various groups of specimens. This was done by assuming that, for a particular level of energy, the thickness at which ignition would barely occur is greater than the thickness which did ignite by the amount: one third the difference in thickness between that which ignited, I, and that which was slightly charred, SC; half the difference in thickness between that which ignited and that which was charred, C; and two thirds the difference in thickness between that which ignited and that which was very charred, VC. Such an estimate is purely arbitrary, but is reasonable and represents the best judgment of the authors.

The critical thicknesses thus chosen are plotted against the corresponding energy levels in Figure 3.3. The energy value of 21.0 cal/cm^2 plotted in Figure 3.3 was furnished by Project 8.1 from data obtained by calorimeters with 90-degree field of view and 100 percent transmission. The energy values less than 21.0 cal/cm^2 were obtained by multiplying this value for 100 percent by the appropriate screen transmission value for the specimen box concerned (Table 3.2). The energy values obtained by Project 8.2, shown in Table 3.1, using 45-degree field of view did not provide valid information that could be used for this purpose.

Previous laboratory work (Reference 4) indicated a power relation between the critical ignition energy and the thickness of the material irradiated. On the basis of the laboratory

TABLE 3.1 THERMAL MEASUREMENTS AT SITE GEORGE, SHOT CHEROKEE

Calorimeter Location	Screen Transmission	Radiant Energy*
	pct	cal/cm²
Tree†	100	5.7
Tree	66.3	2.9
Tree	66.3	2.4
Box‡	66.3	5.5
Tree	48.5	3.7
Tree	48.5	2.1
Tree	37.0	0.9

* Measurements by calorimeters with a field of view of 45 degrees.
† Calorimeter mounted on A frame as shown in Figure 2.6, with detail shown in Figure 2.9.
‡ Calorimeter mounted in specimen box as shown in Figure 2.10.

TABLE 3.2 THERMAL EFFECTS ON URBAN AND FOREST FUELS AT SITE GEORGE, SHOT CHEROKEE

Code: -, No specimen tested; I, Sustained ignition; GI, Glowing ignition; VC, Very heavily charred; C, Charred; SC, Slightly charred; N, No thermal effect.

Incident Radiant Energy	Screen Transmission*	Moisture Content	Cotton Denim	News-paper	Rayon Cloth	Corrugated Fiberboard	Grass	Pine Needles
cal/cm²	pct							
21.0†	100	low	C	-	VC	-	-	I
14.0	66.8	low	SC	-	VC	-	-	SC
13.9	66.3	low	N	I	C	C	SC	C
10.2	48.5	low	N	SC	SC	-	N	N
9.3	44.3	low	N	SC	SC	-	N	N
7.8	37.0	low	-	N	-	N	N	-
6.8	32.4	low	-	SC	N	N	N	N
5.2	24.7	low	-	N	-	-	N	-
5.0	23.8	low	-	N	-	-	N	-
21.0†	100	high	C	-	VC	-	-	I
14.0	66.8	high	N	-	C	-	-	SC
13.9	66.3	high	N	I	SC	-	SC	N
10.2	48.5	high	N	I	SC	N	N	N
9.3	44.3	high	N	GI	N	N	N	N
7.8	37.0	high	-	N	-	-	N	-
6.8	32.4	high	N	N	N	-	N	N
5.2	24.7	high	-	N	-	-	N	-
5.0	23.8	high	-	N	-	-	N	-

* Measured by Forest Products Laboratory.
† Value of 21.0 cal/cm² corrected for normal incidence furnished by Project 8.1.

TABLE 3.3 CRITICAL IGNITION ENERGY VALUES ESTIMATED FOR VARIOUS MATERIALS EXPOSED TO REDWING SHOT CHEROKEE*

Material†	Minimum Thermal Ignition Energy: Low Moisture Content†	Minimum Thermal Ignition Energy: High Moisture Content†
	cal/cm^2	cal/cm^2
White alpha-cellulose paper	>21.0	>21.0
Blue cotton denim	>21.0	>21.0
Charcoal gray rayon	>21.0	>21.0
Newspaper	12.7	9.8
Corrugated fiberboard	>13.9	>10.2
Yellow grass	>13.9	>13.9
Pine needles	18.5	18.5

*The values for newspaper and pine needles were estimated by considering the effects of radiation somewhat insufficient to cause sustained flaming.

†Reference Table 2.2.

TABLE 3.4 THERMAL EFFECTS ON BLACK ALPHA-CELLULOSE PAPERS, 2.5 PERCENT CARBON, SITE GEORGE, SHOT CHEROKEE

Code: -, No specimen tested; I, Ignition, flaming or glowing; VC, Very heavily charred; C, Charred; SC, Slightly charred; N, No thermal effect.

Paper Number		16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Paper Density		0.55							0.75							
Thickness, mils		3.9	5.9	8.0	9.7	11.6	20.2	30.3	2.1	4.1	6.1	8.3	10.1	12.3	20.3	31.5
Incident Radiant Energy	Screen Transmission*	Moisture Content, 23.1 to 24.3 percent														
cal/cm^2	pct															
21.0†	100	I	I	I	I	I	VC	C	I	I	I	I	I	VC	C	C
13.9	66.3	I	I	I	VC	VC	C	SC	I	I	I	VC	C	SC	N	N
10.2	48.5	I	VC	VC	C	N	N	N	I	C	C	SC	N	N	N	-
7.8	37.0	I	VC	VC	C	N	N	N	I	VC	C	N	N	N	-	-
		Moisture Content, 1.6 percent														
21.0†	100	I	I	I	I	I	I	I	I	I	I	I	I	VC	C	-
13.9	66.3	I	I	I	I	I	C	C	I	I	I	I	VC	VC	C	-
10.2	48.5	I	I	I	I	SC	N	N	I	I	VC	VC	C	SC	-	-
7.8	37.0	I	I	C	VC	N	N	N	I	C	N	N	N	N	-	-

*Measured by Forest Products Laboratory.

†Value of 21.0 cal/cm^2 corrected for normal incidence furnished by Project 8.1.

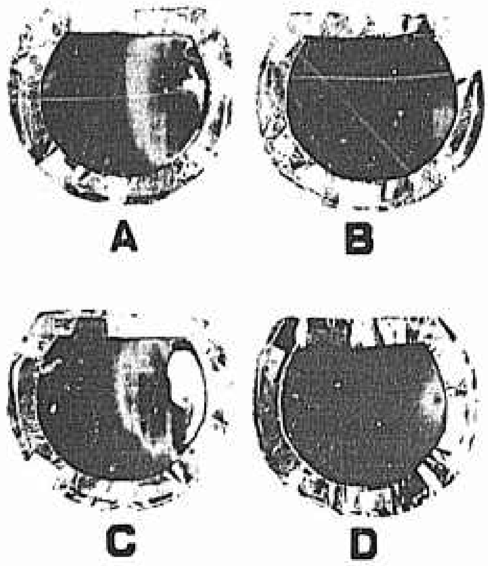

Figure 3.1 Specimens of rayon cloth after exposure to Shot Cherokee. A, very charred, moisture content 1.6 percent, radiant energy 14.0 cal/cm^2; B, slightly charred, moisture content 36.1 percent, radiant energy 10.2 cal/cm^2; C, very charred, moisture content 1.6 percent, radiant energy 21.0 cal/cm^2; D, slightly charred, moisture content, 36.1 percent, radiant energy 13.9 cal/cm^2.

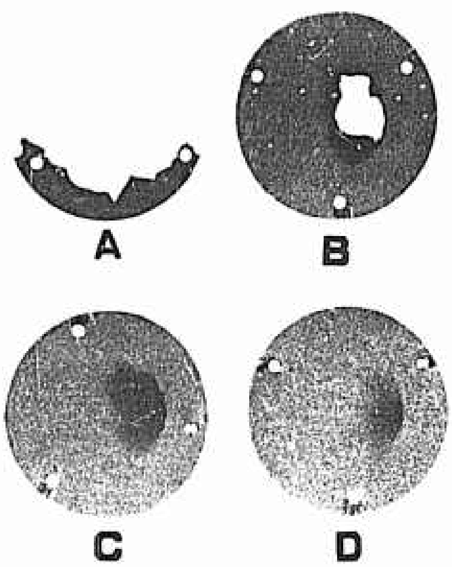

Figure 3.2 Specimens of black alpha-cellulose paper (0.55 sp. gr.) after exposure to Shot Cherokee. Radiant energy, 13.9 cal/cm^2, moisture content, 23 percent. A, ignition, thickness 8.0 mil; B, very charred, thickness 9.7 mil; C, very charred, thickness 11.6 mil; D, charred, thickness 20.2 mil.

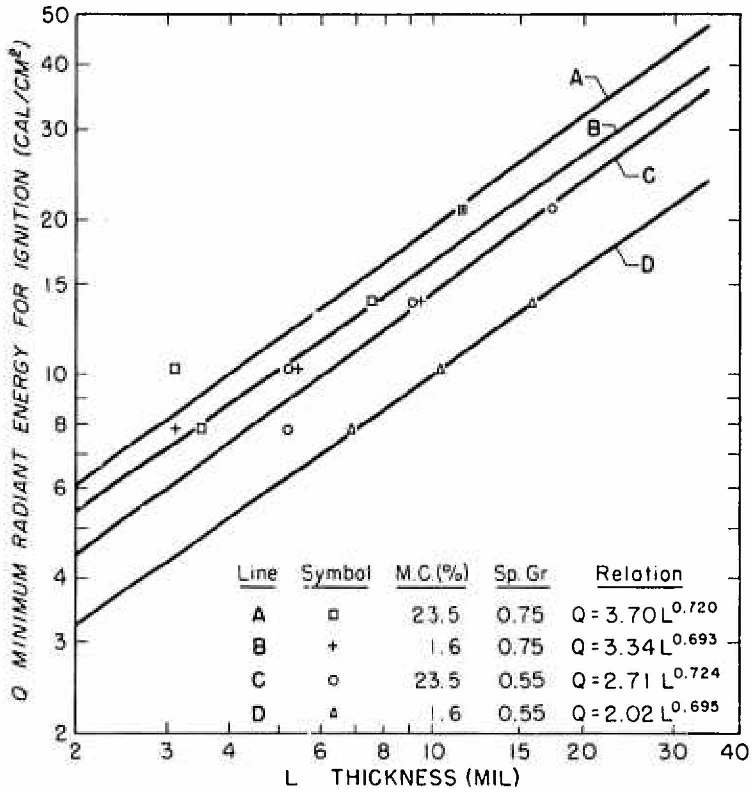

Figure 3.3 Relationship between minimum radiant energy for ignition and thickness of black alpha-cellulose paper.

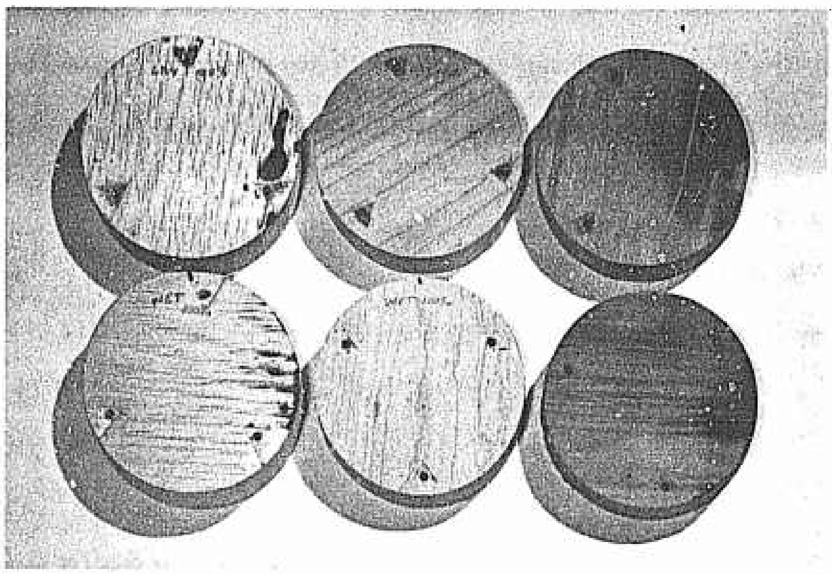

Figure 3.4 Wood specimens after exposure to Shot Cherokee, radiant energy 21.0 cal/cm^2. Top row: left to right, balsa, maple, and willow; moisture content about 1.0 percent. Bottom row: left to right, balsa, maple, and willow; moisture content about 20 percent.

indications, straight lines were drawn to fit the points plotted in Figure 3.3 as closely as possible. The straight line graphs of Figure 3.3 indicate that the slopes of the lines are independent of the magnitude of the energy at least over the range of about 3 mils to 20 mils. (Note: The data on which Figure 3.3 is based are too few, and the points too scat-

TABLE 3.5 CRITICAL IGNITION ENERGY VALUES* FOR BLACK ALPHA-CELLULOSE PAPERS EXPOSED TO SHOT CHEROKEE

Thickness	Specific Gravity	Minimum Thermal Ignition Energy: 1.6 percent Moisture Content	Minimum Thermal Ignition Energy: 23.1 to 24.2 percent Moisture Content
mil		cal/cm²	cal/cm²
3.9	0.55	5.2	7.2
5.9	0.55	7.0	9.8
8.0	0.55	8.5	12.2
9.7	0.55	9.8	14.0
11.6	0.55	11.0	16.0
20.2	0.55	16.3	24.0
30.3	0.55	21.5	32.0
2.1	0.75	5.6	6.3
4.1	0.75	9.0	10.0
6.1	0.75	11.7	13.7
8.3	0.75	14.7	17.0
10.1	0.75	16.7	19.5
12.3	0.75	19.2	22.5
20.3	0.75	27.5	32.0
31.5	0.75	37.0	44.0

* Estimated from Figure 3.3.

tered, to warrant firm conclusions as to the exact relation between critical ignition energy and the thickness of material. More experimental data are needed to substantiate the indications of these data of Project 8.2 and to broaden the range over which the relation is valid.)

Assuming the straight line relation shown in Figure 3.3, critical ignition energy values in Table 3.5 for the various thicknesses of black alpha-cellulose paper exposed to Shot Cherokee were read from the lines in Figure 3.3.

3.4 WOOD SPECIMENS

The appearance of typical wood specimens after exposure to Shot Cherokee is shown in Figure 3.4. No thickness measurements prior to exposure were made on the wood samples near the edges where charring occurred; consequently, no depth-of-char measurements of the wood specimens were possible.

Chapter 4

DISCUSSION

Because the actual air zero was far from coincident with that planned for Shot Cherokee, the radiation on the test specimens was at an appreciable angle from the normal, estimated to be 22 degrees at Site George. The radiant energy per unit area, therefore, was some 7 percent less (cos 22° = 0.93) than it would have been had the direction of incidence been normal. For some of the test materials, particularly grass and pine needles, the direction of incidence is unimportant. For those materials that obey the cosine law, the error due to oblique incidence would be about 7 percent, which is less than the accuracy with which the minimum thermal-ignition-energy values are known.

Sites George and Dog were chosen for the stations of Project 8.2 on the basis of an expected yield. Attenuating screens of particular transmissions were chosen on the same basis. Shot Cherokee, however, proved to have a yield of only 60 percent of that employed as the basis for choosing Sites George and Dog for Project 8.2 and for choosing the screens to attenuate the radiation directed towards the specimens.

The white alpha-cellulose papers, the cotton denim, charcoal-gray rayon cloth, corrugated fiberboard, and yellow fescue grass were not ignited by the level of radiant energy delivered by Shot Cherokee at Site George. If the yield of the nuclear device had been about 40 percent higher, as anticipated in the preshot planning, the energies of critical ignition for these materials would probably have been bracketed by the test exposures.

The fact that no ignition was obtained on the fine yellow grass and the thin white paper, even at low moisture contents, may be due in part to their high reflectances of the wave lengths emitted by the fireball.

Critical ignition energies were obtained within reasonably narrow ranges for the newspaper, pine needles, and the black alpha-cellulose papers.

Within the limitations of the experimental data, the results of tests on the black alpha cellulose paper (Figure 3.3) showed: (1) the higher the moisture content, the greater the minimum radiant energy for ignition; (2) the higher the specific gravity, the greater the minimum radiant energy for ignition; (3) as an approximation, the minimum radiant energy for ignition increased with the thickness raised to about the 0.7 power; (4) moisture content had more effect on the critical ignition energy of the thick papers than of the thin papers; and (5) an increase in specific gravity had more effect on the critical ignition energies of the thick papers than of the thin papers.

The calorimeter results of Project 8.2 are given in Table 3.1 only to indicate that they are not suitable for the original objectives. Because of the considerable bombing error, the field of view of the sensitive elements of the calorimeters covered largely sky immediately adjacent to the fireball and included only a portion of the fireball itself. The mountings for these instruments were not designed to provide perfect alignment, and since the edge of the field of view of the calorimeters approximated the edge of the fireball in Shot Cherokee, the sharp gradient in the radiation scattered by the atmosphere near the fireball and the discontinuities in the scattering clouds resulted in large variations in the energies measured by each instrument. No conclusions, therefore, can be drawn from the calorimeter results as to the radiant energies incident on the test specimens or the effectiveness of the screens in attenuating the radiation from the fireball.

The use of primacord and counterbalancing weights to trigger a physical action, such as the opening of specimen boxes just before shot time, was an innovation tried for the first time by Project 8.2 during Operation Redwing. The method proved to be simple and reliable and was preeminently successful in these tests. By this method it is feasible to expose dry specimens in the humid atmosphere prevailing at the EPG.

Chapter 5
CONCLUSIONS

Minimum-thermal-ignition energy values were obtained within limits for newspaper and pine needles and black alpha-cellulose papers of different specific gravity and thicknesses.

The higher the moisture content of a combustible material, the more radiant energy is required to ignite it.

The greater the specific gravity of a combustible material, the more radiant energy is required to ignite it.

Moisture content and specific gravity had more effect on the critical ignition energies of thick materials than of thin materials.

With radiation of the spectral distribution from Shot Cherokee, the white paper was much less susceptible to charring than the black paper, also the light-colored yellow grass was less susceptible to ignition than the dark-brown pine needles.

As a tentative conclusion from relatively little data, for the thickness range from 3 to 20 mils, energy required for ignition of black alpha-cellulose paper increased with thickness, raised to about the 0.7 power.

Instead of locating specimens at many distances from ground zero to vary the incident radiant energy for ignition study, the specimens can be located all at one station and the energy attenuated by filtering through screens in front of the specimens.

A new triggering technique by means of explosive primacord proved successful.

A method of exposing dry specimens was tried and found satisfactory.

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